Buildings Guide
Upgrade to ultra-low-energy buildings

Strategic Approach

The Strategic Approach to improving energy efficiency in buildings

New residential buildings – Ultra-Low-Energy Buildings

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The Advanced Strategy towards Ultra-Low-Energy Buildings (ULEB)

The concept of Ultra-Low-Energy buildings is a further development of a Low-Energy Building, requiring up to 90% less energy than a conventional new building. In the bigEE project, the term Ultra-Low-Energy Building is used for buildings with a primary energy consumption for heating, cooling, ventilation and hot water of between:

• 20 to 40 kilowatt-hours per square metre of treated floor area per year (kWh/m2 TFA/year) for cold and temperate climate zones,

• 25 to 50 kWh/m^2 TFA/year for hot and arid climate zones and

• 50 to 100 kWh/m^2 TFA/year for hot and humid climate zones (where additional dehumidification is required).

The corresponding final energy consumption for fuel (gas, oil or biomass) and electricity must fall significantly below these limits.

Due to the scope of the bigEE project, as well as the vast areas of the climatic regions covered, the absolute values set for the primary energy consumption are to be seen as the maximum recommended level. These consumption levels are considered representative for regions with the greatest potential for energy saving according to future population and building growth. However these maximum energy consumption levels might have to be adjusted according to actual climatic conditions. In some climatic regions for example, such as in temperate and hot climates, there are so called „lucky climates", where with little or no effort all buildings are (nearly) Zero-Energy Buildings. Here "credits" by using the maximum levels of energy consumption should not be given. Instead the absolute values used to define the LEB and ULEB standards should be based on the Strategic Approach. This is defined as savings in energy consumption against a comparable conventional building whereby for LEB a reduction in consumption of 40% to 60% and for ULEB a reduction in consumption of 60% to 90% are recommended.

Compared to conventional new buildings, ULEBs have:

- Energy saving potential of 60 to at least 80% (and in many cases up to 90%)
- High levels of insulation
- Slightly higher or low extra capital costs if well designed
- Lower utility costs
- Lower lifetime costs if well designed
- Increased thermal comfort
- Enhanced indoor air quality

The golden rule of the ULEB[1] concept is, first, to avoid thermal losses (in cool and temperate climate zones) and/or prevent the penetration of out-door heat (in hot climate zones) and, secondly, to optimize free thermal heat and/or cooling gains.

To achieve ULEB standards, the following principles apply:

Closed concept:

a) Hot and Humid climate zones

- Compact building form but slightly elongated
- East-west orientation of the building with larger façades facing towards north and south, smaller window areas westwards and eastwards
- Effective external shading elements to avoid overheating
- No thermal bridges
- Air tightness proven by a blower door pressure test
- Exceptional thermal insulation (e.g. 10 to 40 cm insulation thickness particularly for roof but also for outer walls, depending on local climate conditions)
- High solar reflectance index (0.6-0.8) of roof surface.
- Windows: Double low-e-glazing (UWindow-values equal or less than 1.3 W/m^{2}K) with the use of solar protective coatings to reduce solar gain.
- Providing space cooling by cooling the supply air e.g. through controlled mechanical ventilation with energy recovery systems (> 75% of recovery) and efficient drives (≤ 0.45 Watt-hours electricity consumption per cubic metre volume flow)[2]
- In case the cooling demand is not being met by supply air system (all air system), cooling may be done using water as the medium for cooling distribution withing the building (air-water system)
- Effective dehumidification technologies
- Energy-efficient cooling backup system for covering the residual cooling energy consumption if necessary (if possible with renewable energy sources)
- Solar hot water systems.
- Highly energy-efficient lighting and appliances to minimise internal heat gains
- Quality assurance of construction work
- Occupant's' briefing and building energy management

[1] Design **Recommendations** for Ultra-Low-Energy Buildings can be found in the Buildings Guide of the bigEE.net platform when selecting a type of building and climatic zone in the **Recommendations** section. Details going further than the recommendatuions on the design **Options** for improving the energy efficiency in new residential buildings in a way that an Ultra-Low-Energy standard can be achieved can be found under the section **Options** in the Buildings Guide of the bigEE.net platform.
[2] Heat recovery systems can reach a coefficient of performance (COP) of more than 15. That means that with one kilowatt electric power more than 15 kilowatt thermal energy can be recovered [PHI 2008].

b) Hot and Arid climate zones

- Compact building form but slightly elongated
- East-west orientation of the building with larger façades facing towards north and south, smaller window areas westwards and eastwards
- Effective external shading elements to avoid overheating
- No thermal bridges
- Air tightness proven by a blower door pressure test
- Exceptional thermal insulation (e.g. 10 to 40 cm insulation thickness particularly for roof but also for outer walls, depending on local climate conditions)
- High solar reflectance index (0.6-0.8) of roof surface.
- Windows: Double low-e-glazing (UWindow-values equal or less than 1.3 W/m^2K) with the use of solar protective coatings to reduce solar gain.
- Providing space cooling by cooling the supply air e.g. through controlled mechanical ventilation with heat recovery (> 75% of recovery) and efficient drives (≤ 0.45 Watt-hours electricity consumption per cubic metre volume flow)[3] as well as humidifier for return air.
- Controlled night purge ventilation when temperature permits, in conjunction with mechanical ventilation.
- If higher cooling powers are required then it can be provided by the supply air system using water as a medium for cold distribution within the building.
- Energy-efficient cooling backup system for covering the residual cooling energy consumption if necessary (if possible with renewable energy sources)
- Solar hot water system
- Highly energy-efficient lighting and appliances to minimise internal heat gains
- Quality assurance of construction work
- Occupant's' briefing and building energy management

c) Temperate climate zones

- Compact building form
- East-west orientation of the building with slightly larger façades and large windows facing towards the equator, smaller window areas westwards and eastwards, and few or no windows facing away from the equator
- No thermal bridges
- Air tightness proven by a blower door pressure test
- Exceptional thermal insulation (e.g. up to 40 cm insulation thickness for roof and outer walls, depending on local climate conditions)
- Windows: Double low-e-glazing (UWindow-values equal or less than 1.3 W/m^2K) for climates like Athens (ca. 1200 HDD18°C) or triple low-e-glazing (UWindow ≤ 0.8 W/m^2K) for climates like Frankfurt (ca. 3200 HDD18°C) with a minimum g-value[4] of 0.6
- External shading to avoid summer overheating
- Controlled mechanical ventilation with heat recovery (> 75% of recovery) and efficient drives (≤ 0.45 Watt-hours electricity consumption per cubic metre volume flow)[5]

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[3] Heat recovery systems can reach a coefficient of performance (COP) of more than 15. That means that with one kilowatt electric power more than 15 kilowatt thermal energy can be recovered [PHI 2008].

[4] "g-value" is the coefficient commonly used in Europe, while Solar Heat Gain Coefficient (SHGC) is used in the United States. Both measure the solar energy transmittance through windows and range from 0 (0% transmittance) to 1 (100% transmittance).

[5] Heat recovery systems can reach a coefficient of performance (COP) of more than 15. That means that with one kilowatt electric power more than 15 kilowatt thermal energy can be recovered [PHI 2008].

- Energy-efficient heating / cooling backup system for covering the residual heating / cooling energy consumption if necessary (if possible with renewable energy sources)
- Energy-efficient hot water system (if possible with renewable energy sources)
- Highly energy-efficient lighting and appliances
- Quality assurance of construction work
- Occupant's' briefing and building energy management

d) Cool climate zones

- Compact building form
- East-west orientation of the building with large windows facing towards the equator, smaller window areas westwards and eastwards, and few or no windows facing away from the equator
- No thermal bridges
- Air tightness proven by a blower door pressure test
- Exceptional thermal insulation (e.g. 10 to 40 cm insulation thickness for roof and outer walls, depending on climate zone
- Windows: Triple low-e-glazing (UWindow ≤ 0.8 W/m2K) with a minimum g-value[6] of 0.6
- External shading elements to avoid summer overheating.
- Controlled mechanical ventilation with heat recovery (> 75% of recovery) and efficient drives (≤ 0.45 Watt-hours electricity consumption per cubic metre volume flow)[7]
- Energy-efficient heating backup system for covering the residual heating / energy consumption if necessary (if possible with renewable energy sources)
- Energy-efficient hot water system (if possible with renewable energy sources)
- Highly energy-efficient lighting and appliances
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[6] "g-value" is the coefficient commonly used in Europe, while Solar Heat Gain Coefficient (SHGC) is used in the United States. Both measure the solar energy transmittance through windows and range from 0 (0% transmittance) to 1 (100% transmittance).

[7] Heat recovery systems can reach a coefficient of performance (COP) of more than 15. That means that with one kilowatt electric power more than 15 kilowatt thermal energy can be recovered [PHI 2008].

The Blower door pressure test

A pressure test is a crucial element to verify the design and construction of the airtight envelope which is essential for a closed concept ULEB. An airtight envelope is indispensible for the optimal functioning of a controlled ventilation system. The “Blower Door Test” measures the building’s air-tightness. For this purpose, a fan is hermetically sealed into a taut vane in the door opening of an outer door (see Figure 1). The fan builds up an excess pressure of 50 Pascal[87]. The measured mass flow-rate through the fan corresponds to the air flow leaking through the house’s air gaps. The unit of measurement, the n50-value, is given in multiples of the building volume per hour. In buildings with a controlled ventilation system, the n50-value should not exceed 1.5 h-1 for systems without and 0.6 h-1 for systems with heat (or cold) recovery. If the values are above the limit, air gaps must be detected and thoroughly closed. (HMUELV 2011b)

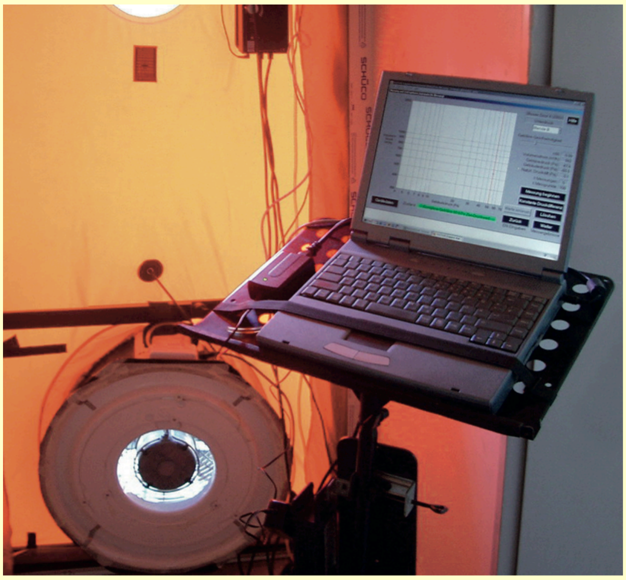

Figure 1: Blower door test | Source: Schüwer (2012)

Open, hybrid and zoned concepts

In addition to the hermetically sealed closed concept, open, zoned or hybrid concepts may also achieve the ultra-low energy standard in hot climate zones, particularly hot and humid regions. These concepts rely on natural ventilation driven by thermal buoyancy or by zoning rooms with different thermal comfort requirements. For detailed information on these as well as the closed concept please see the Recommendations as well as the Options on the bigEE Website.

Example of an Ultra-Low-Energy Building: The Passive House concept

The most mature and prominent example of an Ultra-Low-Energy building is the Passive House (PH). Because it was developed in Germany, a climatic region with rather cold winters and mild summers, the key elements associated with a PH are an air-tight super-insulated building envelope with mechanical ventilation and heat recovery. This technical approach is optimized for wintry conditions but also avoids overheating in summer and thus provides all-year thermal comfort (see Figure 2). In hot climate zones, the basic requirements adapt to the provision of cooling rather than heating. The Passive House’s energy consumption is reduced to a point where thermal comfort can be guaranteed solely by heating (or cooling) only the amount of supply air, which is required for good indoor air quality (Schnieders 2009). With this basic approach, a conventional heating or cooling system can be significantly scaled down or even completely omitted. That is why a Passive house is one of the most cost-efficient building standards in terms of life cycle costs (see also Figure 3).

[8] Corresponding to a wind pressure of about 4 to 5 on the Beaufort scale.

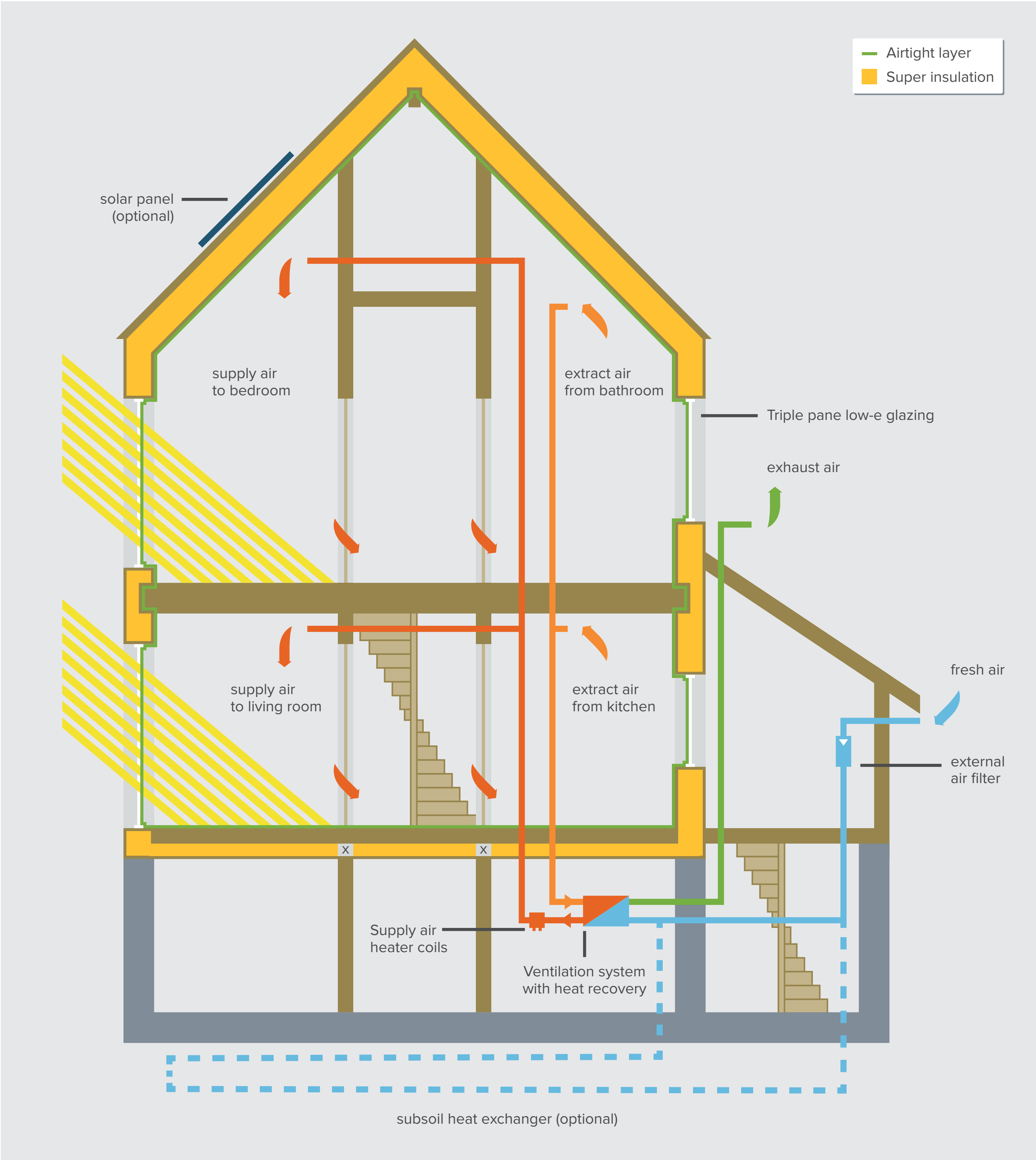

Figure 2: Sectional drawing through a Passive House, with additional pre-heating of the supply air using a ground coupled heat exchanger (earth tubes)
Source: Wuppertal Institute, adapted from Passive House Institute (2012a)

In addition to the basic ULEB principles outlined above, the following requirements are essential for the Passive House concept with active heating / cooling by mechanical ventilation only:

- Exceptional air tightness. The building must not leak more air than 0.6 times the house volume per hour, measured at a pressure difference of 50 Pascal (n50 ≤ 0.6 h-1). This must be proven by a pressure test, also called “Blower door test” (see Infobox).

Heating with supply air is limited to a maximum temperature of 55°C, beyond which dust carbonisation sets in. Otherwise, to obtain good indoor air quality normally an air change rate of around 0.3 to 0.4 per hour (equivalent to about 30 m^3 per hour per person) is sufficient [Schnieders 2009]. As a result of these two criteria, a maximum heat output by the ventilation system of about 10"Watt per square metre of treated floor area (TFA) can be realised. This leads to the following requirement:

- The maximum **useful energy** consumption for space heating must not exceed 15 kWh/m^2/year (resulting in - at most - 40"kWh_{PE}/ /year primary energy consumption including ventilation and hot water (HMUELV 2011a (table p.18)). The same limit applies for cooling.

To obtain the certified label Passive House[98], a further condition must also be complied with:

- The maximum **primary energy** consumption including ventilation, hot water and total household electricity (cooking, lighting and all appliances) must not exceed 120 kWh/m^2/year.

This requirement is valid for all types of buildings. However, for residential buildings, a lower level should be aimed for: Assuming a specific primary energy consumption of about 40 kWh/m^2/year for heating, hot water and ventilation with an additional 40 kWh/m^2/year for the operation of highly efficient household appliances and lighting[910], a total of 80 kWh/m^2/year can be achieved in cool and temperate climates. The most important advantages of the Passive House concept are the all-season superior thermal comfort and air quality conditions and cost-effectiveness due to the absence of conventional heating or cooling systems (see Figure 2 and Figure 3).

[9] For the calculation and certification of a PH the purpose-built software "Passive House Planning Package (PHPP)" has been developed. The software is available in different languages.

[10] 40 kWhPE/m^2/year corresponds to a specific electricity consumption of 16 kWhel/m2/year (global PER of 2.5) and results for the example of a dwelling of 120 m^2 treated floor area in an annual electricity consumption of around 1900 kWh_{el}.

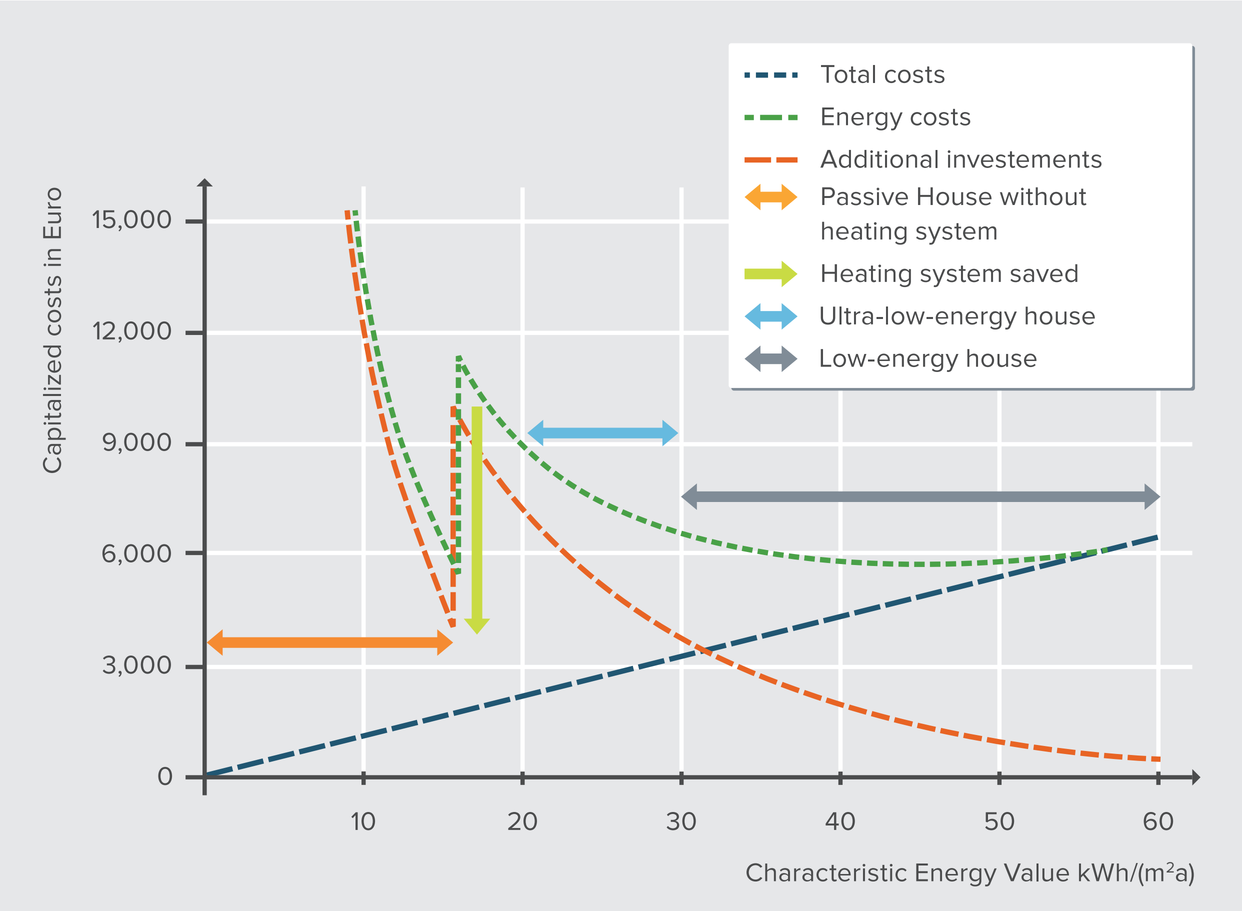

Figure 3: Capitalised costs of saving and supplying heating energy as a function of the specific heat energy consumption: Due to omitting a heating system at the limit of 15 kWh/m^2/year, the total costs of a Passive House fall to a cost optimum level that is lower than for buildings with an inferior energy standard.
Source: Wuppertal Institute, adapted from Passive House Institute (PHI) (2010)

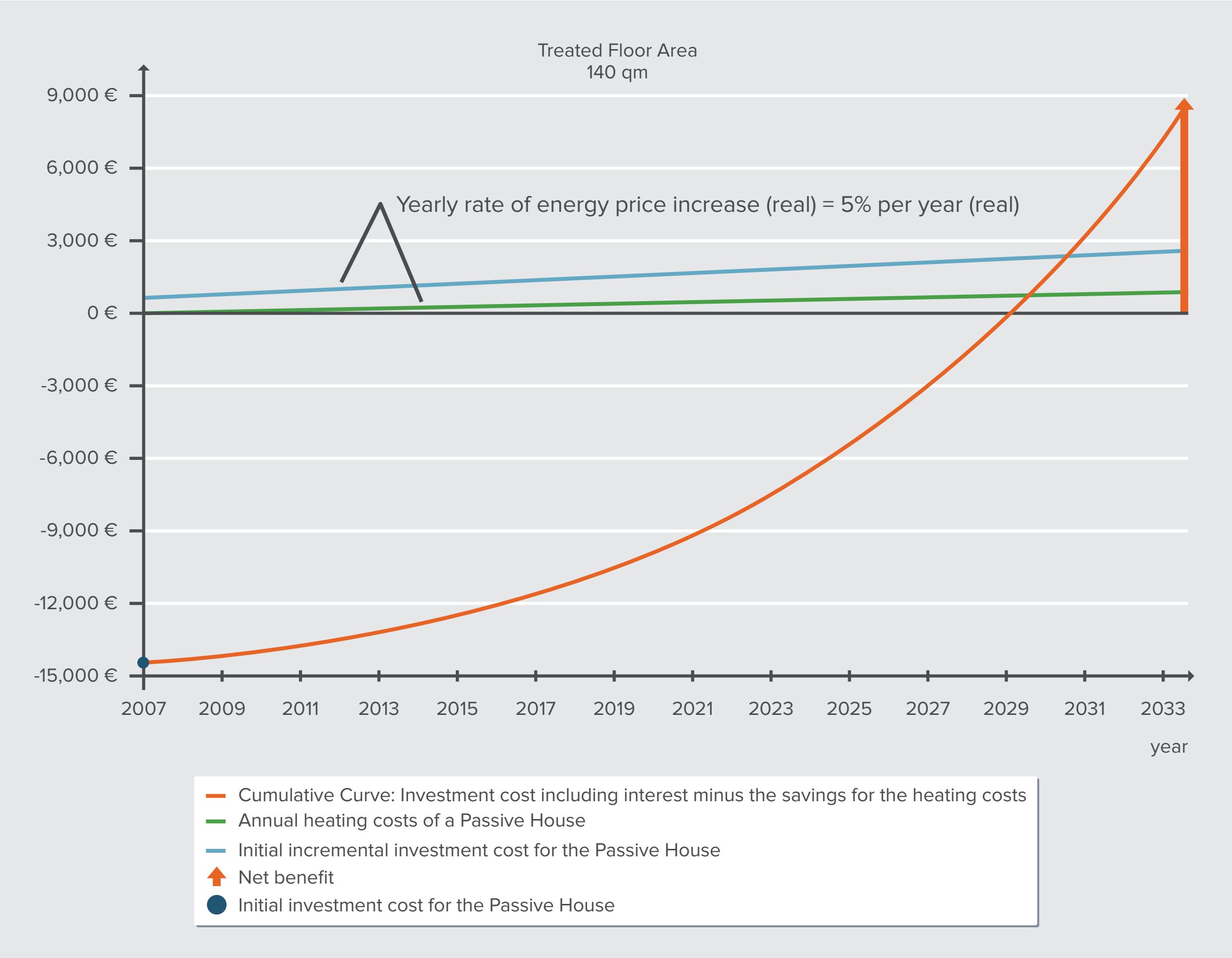

Figure 4: Amortisation of a Passive House with 15 000 Euros of extra initial capital cost (vs. German legal building efficiency standard EnEV 2007): After 22 years the sum of extra costs including accrued interest is compensated by the energy cost savings. Five years later a profit of 9000 Euros is realised.
Source: Wuppertal Institute, adapted from HMUELV (2011a)

The first passive house was constructed in Darmstadt, Germany, in 1991. Today, in Europe alone, more than 35,000 residential and commercial buildings have been built to the Passive House standard in solid and lightweight construction. According to the Passive House Institute, those buildings save annual energy costs of about EUR 175 million and CO_2 emissions of about 200,000 tons (PHI 2011). Even in extreme climate zones like high mountain areas (e.g. Alpine refuge "Schiestlhaus" in Hochschwab/Austria, situated at an altitude of 2,154 m above sea level; cf. Figure 5), buildings successfully use Passive House technologies.

Figure 5: Example of realised Passive House concept under extreme conditions: Alpine refuge "Schiestlhaus" in Hochschwab/Austria
Source: Petra Blauensteiner (2006)

The Passive House concept ensures thermal comfort not only in the winter of cold temperate climate zones, but also in the summer of warmer temperate zones. The EU-Project Passive Houses in Mediterranean Climates examined the summer performance of Passive Houses in the warmer climates of south-west Europe [Schnieders 2009]. Figure 6 shows the Passive House provides far better thermal comfort than buildings with poor insulation.

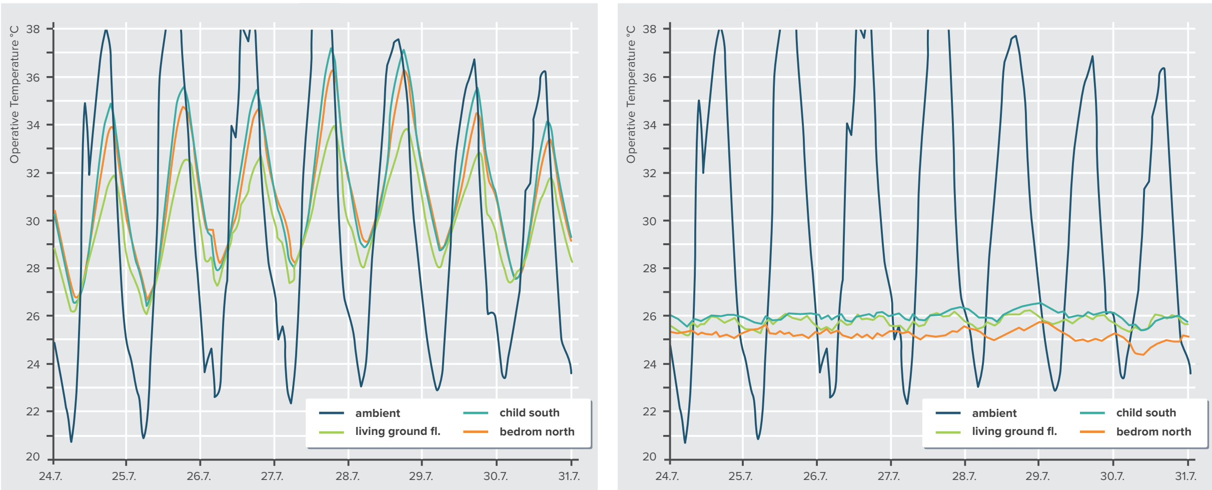

Figure 6 :
a) A poorly insulated existing building, with exterior blinds and full night ventilation: unbearable conditions.
b) Summer temperatures in a Passive House in Seville, with good insulation (8 cm wall, 20 cm roof) and supply air cooling: The design indoor temperature of 26° is hardly exceeded, thermal comfort is provided.
Source: Wuppertal Institute, adapted from Schnieders (2009)

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Your guide to energy efficiency in buildings.

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bigEE is an international initiative of research institutes for technical and policy advice and public agencies in the field of energy and climate, co-ordinated by the Wuppertal Institute (Germany). Its aim is to develop the international web-based knowledge platform bigee.net for energy efficiency in buildings, building-related technologies, and appliances in the world's main climatic zones.

The bigee.net platform informs users about energy efficiency options and savings potentials, net benefits and how policy can support achieving those savings. Targeted information is paired with recommendations and examples of good practice.

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